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Measurement of the top quark mass from the leptons' $\mathrm{P_T}$ in the $\mathrm{t\bar{t}} \rightarrow$ dilepton channel using b-tagging at 2.8 fb^{-1}

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Abstract

A new measurement of the top quark mass at 2.8 fb^{-1} integrated luminosity, using the leptons' $\mathrm{P_T}$ is presented. The events are selected in the dilepton decay channel where at least one tagged jet is required. A top quark mass of $\mathrm{M_{top}} = 154.6 \pm 13.3_{\mathrm{stat}} \pm 2.3_{\mathrm{syst}}\ \mathrm{GeV/c^2}$ is obtained.

1 Introduction

This note presents a measurement of the top quark mass in the dilepton channel using 2.8 fb^{-1} of data. The results presented are obtained using data collected by the CDF detector in $\bar{p}p$ collisions at $\sqrt{s} = 1.96$ TeV with the CDF detector at the Fermilab Tevatron. The CDF detector is described in detail in [1]. The top quark mass is measured using only the lepton's P_T information as proposed in [2]

The leptons' P_T is a variable that can be measured very well in the tracker and the calorimeter and can be accurately calibrated against Z$\rightarrow$ dilepton decays. Jets have a minimal involvement in this analysis, i.e. only in the criteria used for the event selection. Therefore the top quark mass as extracted through this method, is associated with a low JES uncertainty. The leptons P_T is a simple variable that is common in the dilepton and the lepton+jets channels, a fact that that gives the opportunity to directly compare the results from the two channels and also combine them. Similar measurements have been presented and approved by the CDF for both channels. It was first implemented for the lepton+jets channel at the low luminosity of 340 pb^{-1} [4] and again at 2.7 fb^{-1} [5] using b-tagging, and improving signicantly both the statistical and the systematic uncertainties to $M_{top} = 172.1 \pm 7.9_{(stat)} \pm 3.0_{(syst)}$ GeV/c^2. The first measurement in the dilepton channel used 1.8 fb^{-1} of data and no b-tagging [6]. This top mass measurement gave $M_{top} = 156.2 \pm 20 \pm 4.6$ GeV/c^2.

The measurement is based on the identification of both leptons in the decay chain $t\bar{t} \rightarrow (W^+b)(W^-\bar{b}) \rightarrow (l^+\bar{v}_l b)(l^- v_l \bar{b})$, where at least one jet is tagged. Therefore it selects decays with two high transverse energy leptons, high missing transverse energy ($\not{E}_T$) and at least two jets in the final state. The excess of events selected in the data over the background expectation from the other known Standard Model sources is taken as a measurement of the production of $t\bar{t}$ events.

2 Data Sample & Event Selection

This analysis is based on the data collected with the CDFII detector between March 2002 and May 2008 with total integrated luminosity of 2.8 fb^{-1} . The data are collected with an inclusive high-E_T central electron or muon trigger path. From this inclusive lepton dataset, events containing a pair of oppositely charged isolated leptons with $E_T \geq 20$ GeV are selected. Each central lepton is identied as a reconstructed stiff track matched to either calorimeter electromagnetic shower in case of electrons or calorimeter towers with small energy response consistent with minimum ionizing particle in case of muons. This dilepton dataset is cleaned of other known neutrino - less events with two leptons in the final states by requiring $E_T \geq 25$ GeV. For the purpose of our selection we define jets as the clusters of calorimeter energy separated from leptons and passing $E_T \geq 15$ GeV requirement in the $|\eta| < 2.5$ region of the detector. In order to purify the signal events we require at least two jets one of which has 30 GeV or more in transverse energy. In addition to this we use a higher purity conguration of the secondary vertex tagger to identify at least one jet in the event as a b-jet, the algorithm known as b-tagging. The details of the selection are documented in [3].

3 Backgrounds

The sources of background processes considered in this selection are diboson (WW, WZ and ZZ) events, $q\overline{q} \rightarrow Z/\gamma^*$ and fake or QCD background events.

The fake or QCD background is the dominant source and is estimated from the data events with same sign. By doing so it is assumed that the same charge lepton pairs occur at the same rate as the oppositely charged lepton pairs in data sample, where at least one lepton is not originating from W or Z leptonic decay. The spectrum of the fake leptons P_T is derived from W+$b\bar{b}$ +jets ALPGEN+PYTHIA samples as it contains the two b-quarks that also exist in the $t\bar{t}$ final state. Therefore this physical process is the one that is most probable to exist as a background in our final state. The diboson, $Z/\gamma^* \rightarrow \tau\tau$ and $Z/\gamma^* \rightarrow ee/\mu\mu$ decays are simulated with PYTHIA.

This dilepton b-tagged event selection that is applied is almost background-less. For $\mathcal{L}$=2.8 fb^{-1} only 4±1.7 background events are expected over 80 dilepton data events. Two of the background events originate from QCD processes and the two remaining are from the DY and diboson processes. The expected signal to background ratio for this selection is 16.3.

4 Description of the Method

This analysis has been based upon the observation that the leptons' transverse momentum P_T is sensitive to the top mass [2], [4], [5], [6]. Figures 1 and 2 show that the dependence of the mean P_T of the leptons to the mass is linear.

$$P_T = \kappa + \lambda M_{top} \tag{1}$$

In Figure 1 the lepton mean P_T vs the top mass is shown. The leptons' mean P_T is derived from the P_T distributions of the mass signal templates generated for different input top masses. In Figure 2 each signal template has been combined to the total background template taking into account that the purity of the total sample, as calculated for Mtop = 175 GeV, is for $\rho \equiv \frac{\text{signal}}{\text{signal+background}} = 0.94$. Taking the extreme case that only signal exists the sensitivity $\frac{d\langle P_T\rangle}{dM_{top}}$ is $\lambda_S = 15.1 \pm 0.5\%$. Including the background, as seen from Figure 2, the sensitivity is reduced to $\lambda_B = 14.3 \pm 0.4\%$. This decrease in the slope is expected since the background contaminates the Monte Carlo samples with events involving no top quarks and thus carrying no M_{top} information. This can be seen by decomposing the $\langle P_T\rangle$ into a 'signal' $\langle P_T\rangle_S$ and a 'background' $\langle P_T\rangle_B$ part:

$$< P_T >= \rho\langle P_T\rangle_S + (1-\rho)\langle P_T\rangle_B \tag{2}$$

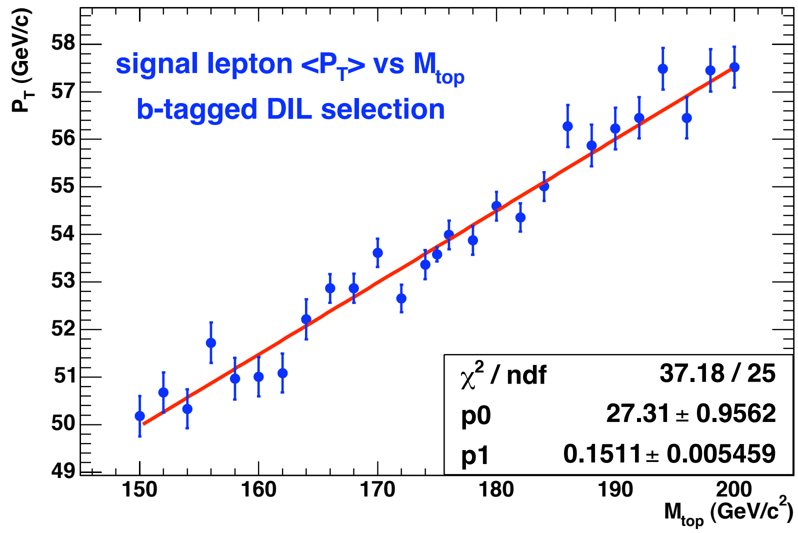

Figure 1: Lepton mean P_T sensitivity to the top mass form signal only P_T distributions, where b-tagged dilepton selection was applied.

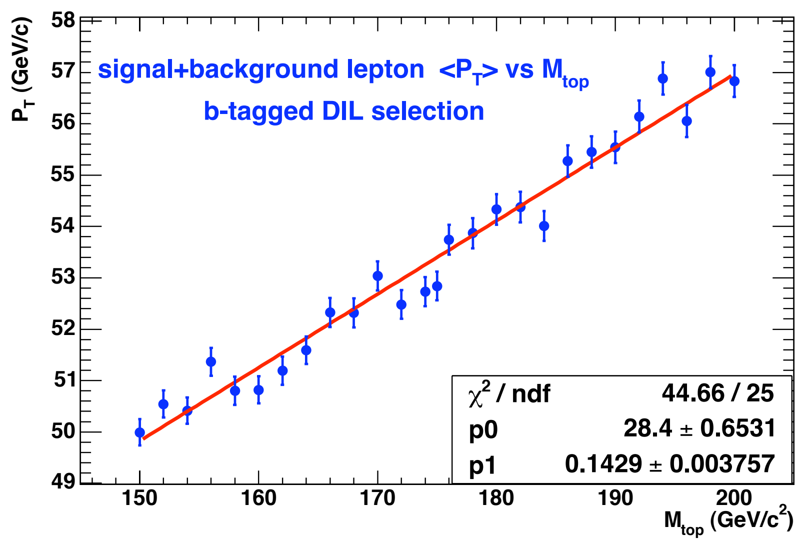

Figure 2: Lepton mean P_T sensitivity to the top mass form combined signal and background P_T distributions,where b-tagged dilepton selection was applied.

Going to a deeper level, we model the leptons' P_T distribution with an analytical function to examine how this function depends on the top mass. We found that such a function can be the product of a Gamma times a Fermi function as shown in Equation

3:

$$\mathrm{F(P_T)} = \frac{1}{\Gamma(\mathrm{p}+1, \mathrm{c/q})} \left(\frac{\mathrm{P_T}}{\mathrm{q}}\right)^{\mathrm{p}} \mathrm{e}^{-\frac{\mathrm{P_T}}{\mathrm{q}}} \times \frac{1}{1+\mathrm{e}^{\mathrm{c}-\mathrm{P_T/b}}} \tag{3}$$

This function models successfully the shape of both the signal and the background $\mathrm{P_T}$ distributions. It has two free parameters p, q, where p is related to the expected rate of leptons with the average $\mathrm{P_T}$ and q can be interpreted as the expected average $\mathrm{P_T}$ per lepton. For the signal the p, q are mass dependent (see Eq. 4, 5) but for the background they are constant. The Fermi function models the leptons' $\mathrm{P_T}$ cut, setting c=20GeV/c and b=0.1GeV/c. The p and q are parametrized as in the following equations

$$\mathrm{p} = \alpha_1 + \alpha_2 \mathrm{M_{top}} \tag{4}$$

$$\mathrm{q} = \alpha_3 + \alpha_4 \mathrm{M_{top}} \tag{5}$$

The top mass is measured by employing the likelihood minimization procedure. The Gamma x Fermi function is used as a probability density function (p.d.f). To arrive to a final mass estimation the leptons' $\mathrm{P_T}$ values are compared with the signal and background p.d.f's within a likelihood minimization. The likelihood function estimates the probability that a given sample of $\mathrm{P_T}$ values is an admixture of $\mathrm{t\bar{t}} \rightarrow$ dilepton and background decays with a given top mass. Therefore, a probability $\mathrm{P_s(P_T; M_{top})}$ or $\mathrm{P_b(P_T)}$ is assigned to each lepton with a given $\mathrm{P_T}$ value to look like signal or to look like background respectively. These probabilities are assigned by comparing the $\mathrm{P_T}$ value with the corresponding parametrized p.d.f's P_S and P_B. Furthermore the estimated number of signal n_S and background n_B leptons are constrained to be consistent with the total number of data leptons N through a Poisson parameterization. The estimated number of background leptons are constrained to a-priori background expectation n_B^{exp} within its statistical uncertainty $\sigma_{\mathrm{n_B}}$ using a Gaussian term. The total likelihood function takes the following form:

$$\mathcal{L}(\mathrm{P_T}) = \mathcal{L}_{\mathrm{shape}}(\mathrm{P_T}) \times \mathcal{L}_{\mathrm{Bg}}$$

$$\mathcal{L}_{\mathrm{shape}}(\mathrm{P_T}) = \tfrac{(\mathrm{n_s+n_b})^{\mathrm{N}} \mathrm{e}^{-(\mathrm{n_s+n_b})}}{\mathrm{N}} \prod_{\mathrm{i}=1}^{\mathrm{N}} \frac{\mathrm{n_s P_s(P_T^i; M_{top}) + n_b P_b(P_T^i)}}{\mathrm{n_s + n_b}} \tag{6}$$

$$-\mathrm{ln}\mathcal{L}_{\mathrm{Bg}} = \tfrac{1}{2} \left(\tfrac{\mathrm{n_b - n_b^{exp}}}{\sigma_{\mathrm{nb}}}\right)^2$$

The statistical uncertainty on the top mass is given by the difference between the minimization mass result and the mass at $-ln\mathcal{L}_{max} + 0.5$.

5 Systematic Uncertainties

The systematic uncertainties of this mass measurement can be grouped in four main categories. The first group involves the uncertainties on the top mass related to the signal. The second group is related to the background. The third one deals with the leptons' P_T scale uncertainty. Finally the fourth one is related to the JES uncertainty and the Multiple Interactions.

A. Signal related systematic uncertainties:

- MC statistics
- Gluon radiation in the initial and final state (IFSR)
- Choice of the Monte Carlo generator
- Choice of the Parton Distribution Functions (PDF) for the protons

B. Background related systematic uncertainties:

- Uncertainty because of the background shape
- Uncertainty because of the background constrain

C. Scale uncertainty in the measurement of the leptons' P_T includes:

- the global lepton P_T scale uncertainty and
- the local lepton P_T scale that accounts for possible non linearities

D. Uncertainty on the top mass due to the Jet Energy Scale and Multiple Interactions uncertainties.

The total systematic uncertainty to the top mass is derived by adding in quadrature the partial errors. Table 1 summarizes the systematic uncertainties as well as the symmetrized ones (i.e $\pm\frac{|negative|+positive}{2}$).

6 Data / Results

The final top mass result is corrected for the PDF reweighting, the local and global lepton P_T corrections and an observed overestimation of the top mass of -1 GeV because of a bias in the fit. For the PDF reweighting an event reweighting scheme was applied from the LO CTEQ5L set to the NLO CTEQ6M set, forcing the correct NLO fraction of $gg \rightarrow t\bar{t}$ events relative to $q\bar{q} \rightarrow t\bar{t}$ events [5], [7]. The lepton P_T values were also corrected using global and local correction coefficients. The calibration of the leptons' P_T is described in [5].

source of systematic	δMass (GeV)	$\delta\ Mass^{symmetrized}$ (GeV)
Global P_T scale	-0.10/+0.10	$\pm$0.10
Local P_T scale	-0.40/+1.00	$\pm$0.70
MC statistics	-0.25/+0.25	$\pm$0.25
Generator	-1.50/+1.50	$\pm$1.50
IFSR	-1.28/+1.28	$\pm$1.28
PDF	-0.65/+0.65	$\pm$0.65
Background shape	-0.31/+0.410	$\pm$0.36
Background constrain	-0.20/+0.30	$\pm$0.25
JES	-0.30/+0.50	$\pm$0.40
Multiple Interactions	-0/+0.350	$\pm$0.175
Bias from the fit	- 0.30/+0.30	$\pm$0.30
Total	$\pm$-2.2/+2.5	$\pm$2.3

Table 1: Partial and total systematic uncertainty on the top mass. The second column lists the asymmetric errors and the third column the symmetrized ones, taken as the average of the asymmetric counterparts.

source	Mass correction (GeV)
PDF	+2.9
global lepton P_T scale	+1.6
local lepton P_T scale	+0.9
bias because of the fit	-1.0
TOTAL	+4.4

Table 2: List of the corrections to the top mass.

The b-tagged dilepton selection on the 2.8 fb^{-1} of data gives 80 dilepton pairs. The 160 leptons, give a mean P_T = 49.7 GeV $\pm$ 2 GeV. Figure 3 illustrates the lepton P_T distribution of the data in comparison with the Standard Model signal + background expectation. The Kolmogorov-Smirnov test between the two gives 0.86.

Figure 4 shows the Gamma x Fermi fit to the data. After all corrections listed in Table 2 the top quark mass measured in the b-tagged dilepton channel at 2.8 fb^{-1} , using the full shape of the leptons' P_T , is $M_{top} = 154.6 \pm -13.3_{(stat)} \pm 2.3(syst)$ GeV/c^2. This is one of the best few top mass measurements with regards to the systematic error. This method can potentially be of more interest for the LHC experiments, where a huge number of top candidate events will be registered and the dominating error will, then, be the systematic one. In the circumstance that the leptons will have an accurate calibration soon after the start of data taking, and the energy of the jets a large uncertainty this method is promising one of the first/best top mass measurements.

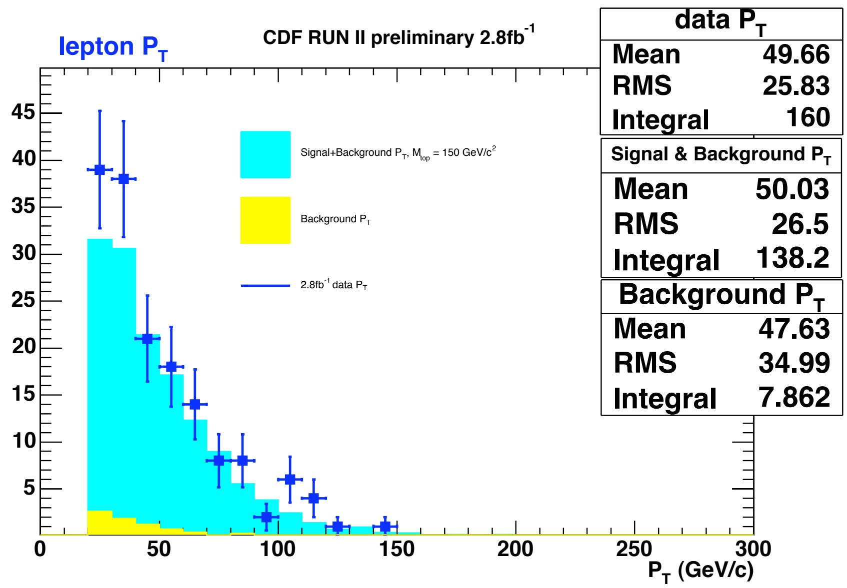

Figure 3: Data leptons' P_T at 2.8 fb^{-1} (blue points). The light blue spectrum corresponds to the leptons' P_T of the MC signal events at M_{top} =150 GeV and the corresponding background. We expect 130.4 signal leptons, estimated for M_{top} = 175 GeV and 8±3.4 background leptons. The total signal and background SM expectation is 138.4 leptons, while the 2.8 fb^{-1} data give 160 leptons.

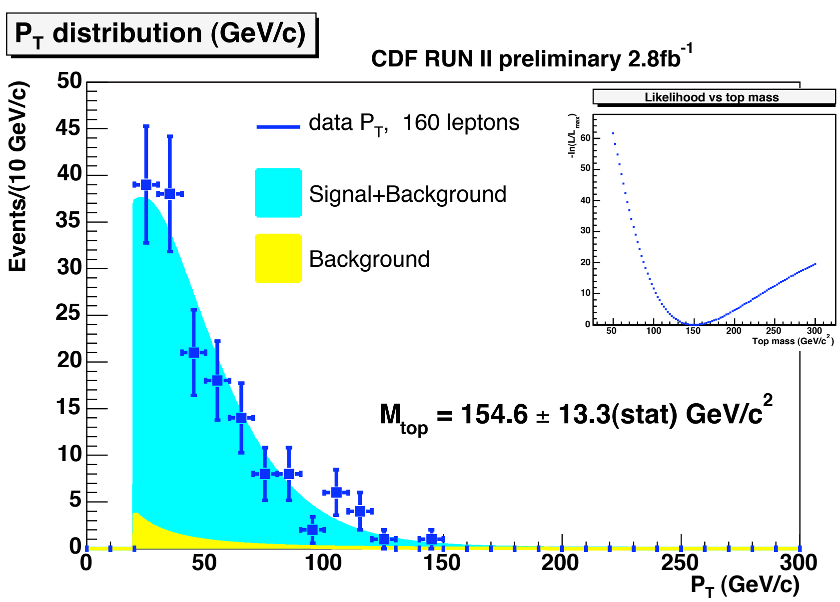

Figure 4: Fit to the 2.8 fb^{-1} b-tagged dilepton data

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